Modeling Approaches in Support of Ecosystem-Based Fishery Management at the Northeast Fisheries Science Center, Woods Hole MA

External Independent Peer Review

by

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Executive Summary

This review focuses on the modeling strategy adopted by NEFSC in support of ecosystem based fishery management (EBFM) and in anticipation of the needs arising from implementation of Ocean Policy. It finds the science reviewed to be of a very high standard and consistent with and in some cases defining and leading current standards of best practice for ecosystem modeling. In particular the overall modeling strategy is comprehensive, well attuned to policy and management needs, and makes maximum use of the excellent ecological and fishery data sets available within the region. A very strong feature of the overall strategy is the use of a diverse set of modeling methods and approaches to address a common set of core issues in EBFM, providing the opportunity for multi-model inference and increasing the robustness of the advice arising. The number and range of models developed and applied in the strategy is particularly impressive given the fairly limited resources invested in this area to date. The review has identified several areas where the strategy could be strengthened. These include a broader focus on direct impacts of fishing on non-target species and on habitats, to complement the current strong focus on trophic interactions and impacts. Further input from the economic and social sciences would also be desirable. Several of the models already show promise or are being used as operating models to support management strategy evaluation, and this feature of the overall modeling strategy should be strengthened ahead of likely increased demand to examine tradeoffs between fisheries and across multiple sector users of the marine environment, arising from impending implementation of EBFM and Ocean Policy strategies. A significant increase in this demand from policy and management would require additional resources to help meet the demand.

Background

Description of the Individual Reviewer's Role in the **Review Activities,**

I was one of three external reviewers for this analysis, the other two being Professor Villy Christensen of the University of British Columbia and Professor Gunnar Stefansson of the University of Iceland. The review panel was selected by the Center for Independent Experts. The reports from each reviewer were written independently. This report was written following a workshop held March 29-31 2011 at the Northeast Fisheries Science Center, Woods Hole, MA to review modeling approaches in support of ecosystem based fishery management. Details of the workshop are described in Attachment 5. Scientific papers and reports relevant to the review are described in Attachment 1. Those provided to the reviewers ahead of the workshop are highlighted as bold in that attachment.

Project Description: The purpose of this review is to evaluate the appropriateness and performance characteristics of community-level and ecosystem models employed at NEFSC as operating models in support of the development of Ecosystem-Based Fishery Management (EBFM) strategies for the Northeast U.S. Continental Shelf. NMFS strongly endorsed the concept of Ecosystem-Based Management and the related need for the development of Integrated Ecosystem Assessment in support of EBFM. The models are also considered in relation to their use to support implementation of Ocean Policy. Although this review is directed at efforts in the NEFSC, the findings will be more broadly applicable throughout the agency. The statement of work for the review provided as Attachment 4.

Summary of Findings

General

This summary of findings pertains to consideration of the overall strategy for developing and applying ecosystem modeling in the NEFSC.

The EM strategy is comprehensive and multi-faceted and appears to be well directed towards regional and national needs. Strong aspects of the strategy include:

- A good understanding of the policy and management context for EBFM and EBM in the region, as well as nationally and internationally;
- A well-considered strategy for moving from current single species or single fishery management structures and plans to an ecosystem approach, and how science and modeling can assist in this transition;
- A comprehensive set of modeling tools across a range of classes of models that in total address the likely range of issues required to move to EBFM;
- A good understanding of the tradeoffs across complexity and accuracy of models and the importance of multi-model inference;
- Recognition of the key role of management strategy evaluation (MSE) and the use of models within this approach to inform tradeoffs across a range of management objectives in support of living marine resource management.

Areas for improvement in the strategy include:

- Broadening the EBFM focus beyond trophic impacts of fishing to include direct impacts on non-target species and benthic habitats;
- Development of models that better integrate economic and social factors in the analysis;
- Further development of models and methods that address multiple uses of the marine environment (in anticipation of needs arising from Ocean Policy);
- Capitalizing on the work already done to present a synthesis of the results of multi-model comparisons against a range of key issues in EBFM;
- Increasing the (already strong) focus on models and capability to support management strategy evaluation in anticipation of needs arising from implementation of EBFM and Ocean Policy.

1. Evaluation, findings and recommendations of overall modeling strategy

B. Summarize evaluations, findings and recommendations of overall community-ecosystem level modeling strategy in practice for the NEUS LME system

The overall modeling strategy at the Northeast Fisheries Science Center (NEFSC) is described in Link et al. (2011) and was presented at the review workshop in the presentation by Mike Fogarty, titled, "Toward Ecosystem-based Fishery Management on the Northeast U.S. Continental Shelf - Review of Modeling Approaches in Support of Ecosystem-Based Fishery Management".

Key aspects of the ecological modeling (EM) strategy include:

1. Capitalizing on the extensive ecological and environmental data sets available in the region;
2. Electing to develop a wide range of models spanning tactical to strategic and with a view to using multi-model comparison and inference;
3. Developing models to serve a range of needs including:
    a. Estimating fishery production potential and system-level biological reference points (BRPs);
    b. Identifying ecosystem overfishing thresholds and criteria;
    c. Providing support for tactical living marine resource (LMR) advice (to improve stock assessments for particular species);
    d. Considering multi-sector use and tradeoffs in the context of ocean policy;
    e. Developing EMs that can be used as operating models in a management strategy evaluation (MSE) context;
4. A process of broad stakeholder engagement including developing a strategy to move from existing management structures to full implementation of an ecosystem based fishery management (EBFM) approach.

With regard to the first element of this strategy, the Northeast US Shelf Large Marine Ecosystem (NES LME) is clearly blessed with some of the best ecological data sets to support EM of any region in the world, and extensive use has been made of these data in the various models reviewed. Notwithstanding the quality and extent of the data, the modeling has identified some key gaps which are noted in Link et al. (2011). Evidence was presented of how these gaps have been used to inform the monitoring strategy for the region, though the extent of uptake of the recommendations was not formally reviewed. Mention was also made of economic and other data (including spatial patterns of use of the marine environment), but these were not reviewed.

The development of a wide set of models and model types (second element in the strategy) is a striking and commendable aspect of the overall EM strategy (see Figure 1 in Link et al. (2011) for the full range of model types developed and their relationship to each other). Although a similar diversity of modeling approaches may be available for some other regions of the world, I am not aware of such a diversity having been developed and applied in one institution and indeed by such a small group of researchers (most of whom are currently in the Ecosystem Assessment Program – EAP – within the NEFSC). The models span the range from tactical (some of the ESAM models) to strategic (e.g. Atlantis) as outlined in the strategy, but also cover both empirical and process based, analytical and statistical, static and dynamic, single to multispecies to energy based, deterministic and stochastic, and simple to complex (see Table 1 in Link et al. 2011). Both individually and in sum, the various models have been used to address most of the needs outlined in element 3 of the strategy (Table 2 in Link et al. 2011). The value of multi-model inference was best illustrated with regard to the issue of system level BRPs (element 3a), with the observation that multispecies maximum sustainable yield (MSMSY) was less than the sum of individual species MSY values being found consistently across a range of models. Several models were also used to address single species assessment issues and in particular the need to estimate predation mortality in assessments and in estimating single species reference points. In my view, more could be made than has been to date of multi-model comparisons and the EAP is in a strong position to do so.

The range of applications of EM outlined in element 3 of the strategy is ambitious and reflects the broader policy and legislative setting in which the work is undertaken. In particular a variety of strategies call for an ecosystem or EBM approach to oceans and fisheries management, including the NOAA Strategic Plan (2005), the President's Executive Order on National Ocean Policy (2010) and, at a regional level, a developing strategy on EBFM through the regional fishery management council process, released as a White Paper by the New England Fishery Management Council in November 2010 (NEFMC 2010).

Although not yet endorsed by the Council, the NEFMC White Paper is an important document that, if endorsed, will be a key determinant of the future strategy for EM in the region. The White Paper outlines the need for EBFM, provides an implementation plan including transition arrangements, points to likely management issues that will need to be addressed, and discusses possible consequences for Council institutions. The longer term strategy envisages EBFM plans based around a small number of Ecosystem Production Units (EPUs). The transition arrangements would retain current Fishery Management Plan (FMP) structures, but would start to "take into account biological and technological interactions and environmental/climate factors that cut across FMPs within defined EPUs … or within FMPs where multiple species are included in the management unit". The longer term strategies would be underpinned by estimates of fishery production potential for each EPU, together with the identification of ecosystem reference points. Components a, b and c of the third element of the EM strategy clearly address these needs, and several of the models developed at NEFSC, and reviewed in this report, already provide a strong basis to provide technical underpinning, both for the transitional arrangements and the longer term strategy.

Element 3d of the EM strategy is designed to address the needs that will emerge under implementation of Ocean Policy. The need for technical support to address multiple uses and conflicts already exists, and is being exacerbated by rapidly emerging new uses of the marine environment such as for wind farms. EM tools that could help to meet this need include models such as Atlantis. A range of tools other than models, including the ability to mobilize data through GIS, will also be needed to address multiple use issues and are currently being provided by NEFSC, but are outside the scope of this review.

Element 3e of the EM strategy – development of operating models that can be used for MSE – is a critical component of the overall strategy that cuts across many other components of the work. It is addressed in more detail in the findings of this section of the report.

Element 4 of the EM strategy involves stakeholder engagement and the identification of strategies to move towards full implementation of EBFM. The latter has already been mentioned in the context of the White Paper, which has been led within the New

England Council process by the Scientific and Statistical Committee (SSC), of which Mike Fogarty is a member. The proposed strategy in the White Paper bears the clear hallmarks of the ideas and concepts presented by members of the EAP at the review. As noted above, there is a clear and strong link between the EM capability on display in the review and the future needs for technical support under the EBFM implementation strategy. There is as yet no clearly defined implementation strategy for Ocean Policy (or at least no such document was presented at the review) and further model development is likely needed to support such a strategy, as outlined further below and in section 2E of this report.

Stakeholder engagement to facilitate uptake of the research is a feature of the EM strategy, particularly through the Scientific and Statistical Committees (SSC) of the two regional Management Councils. A member of the Mid Atlantic Fishery Management Council participated in the review workshop (see workshop attendance list at Attachment 5) and confirmed the active engagement with his Council. Evidence of direct engagement with stakeholders such as the fishing industry, environmental NGOs, and community groups was made available to the review team though not discussed in detail at the workshop. This engagement includes a large number of presentations to councils and to the Atlantic States Marine Fisheries Commission, all of which are public meetings attended by fishers, environmental groups, and other interested parties. It also included 21 regional scoping sessions in 2005 to elicit community views on EBFM. It also includes formal training sessions for fishers and NGO representatives on EBFM through the Marine Resource Education Partnership program. Web-based ecosystem advisory reports have been available since 2006 and an ecosystem website covering much of the work of the EAP was established in January on the NEFSC website.

Findings

The EM strategy is comprehensive and multi-faceted and appears to be well directed towards regional and national needs. Strong aspects of the strategy include:

- A good understanding of the policy and management context for EBFM and EBM in the region as well as nationally and internationally

- A well-considered strategy for moving from current single species or single fishery management structures and plans to an ecosystem approach, and how science and modeling can assist in this transition
- A comprehensive set of modeling tools across a range of classes of models that in total address the likely range of issues required to move to EBFM
- A good understanding of the tradeoffs across complexity and accuracy of models and the importance of multi-model inference
- Recognition of the key role of management strategy evaluation (MSE) and the use of models within this approach to inform tradeoffs across a range of management objectives in support of living marine resource management.

Perhaps the main concern identified in reviewing the overall EM enterprise (rather than the strategy itself) is the limited uptake to date of results from the EM work into practical management outcomes and to some extent into other facets of the work of the NEFSC. This chiefly reflects the fact that although there is much discussion in the region about the value of moving to an ecosystem approach to fisheries management, there are as yet few concrete moves to do so. In this regard the importance of the NEFMC White Paper cannot be underestimated. If the main elements of the plan outlined in the White Paper are adopted by the Council then the EM strategy stands ready to deliver the technical support needed to implement key aspects of it. If the move towards adopting EBFM through the regional councils languishes, then other strategies need to be considered (discussed in more detail below) or the focus shifted to meeting the needs of implementing Ocean Policy.

One feature evident from discussions at the workshop was skepticism and resistance from some stock assessment scientists (one in particular) to incorporating species interaction considerations into single species stock assessments. This also extended to doubts expressed about other aspects of EM results including productive potential and system level BRP calculations. To some extent this reflects healthy debate within the wider NEFSC community and legitimate questions about the robustness of some of the EM models presented. It also probably reflects the pressures under which stock assessment scientists operate, and an awareness of the intense scrutiny that would arise if new models were to be utilized to provide tactical advice, particularly if incorporating species interactions leads to more conservative management advice. As discussed in part two of this report (review of ESAMs but supported by multi-model comparisons) the data and some of the models do appear to be robust enough to incorporate directly into tactical management advice. This is an issue that deserves wider debate at senior levels within NEFSC (which no doubt already happens) but will also hinge on the demand from regional fishery management councils to incorporate such advice.

While most of the EM focus has been on models to support various aspects of EBFM, an emerging need is clearly to support tactical implementation of Ocean Policy. As noted earlier, the need to address aspects of multiple uses and inter-sector conflict already exists (and appears to be a growing issue for fishery management councils). The range of models to support multiple use management is less than the range to support EBFM. However, noting that EBFM is a subset of EBM, the tools and models to support EBFM contribute in part to EBM. Much of the conflict in multiple use plays out in a spatial arena, and spatially resolved models will be required to help address it. In this respect, of the models considered in this review, full system models such as Atlantis that are both spatially resolved and capable of representing multiple uses are likely to play the major role in support of implementing Ocean Policy, particularly as operating models to support MSE analysis of alternative spatial EBM strategies. As discussed in section 2E of this report, the current version of Atlantis used in the NES LME still needs some further development before it could be used to evaluate multiple use management strategies. While alternatives to Atlantis exist to evaluate multiple use management strategies, the investment already made in developing this model for the NES LME suggests that further investment in this particular model may be a sensible strategy, particularly as its highly modular structure allows testing of the robustness of strategies to a wide set of alternative model configurations and assumptions. Some of the simpler models developed in the EM strategy might well be considered as “assessment” models to be adopted as part of overall EB(F)M strategies, and tested in an MSE analysis using Atlantis as the main operating model. As noted earlier, tools other than models (such as GIS and risk assessment) are also likely to play a prominent role in support of implementing Ocean Policy.

Returning to consideration of the EM strategy in support of EBFM, one observation from this reviewer is that the models developed and the questions addressed focus very strongly on what might be described as the "trophic" effects of fishing. This contrasts quite strongly with my experience in using models (and other tools) to address EBFM in Australia, where consideration of the ecological impacts of fishing has much less focus on trophic effects and has more focus on issues such as bycatch and impacts on protected species and benthic habitats. There are several possible explanations for this difference in focus, some of which were discussed briefly at the workshop. With regard to direct impacts of fishing on other species and on habitats, it was explained that these issues are mainly dealt with and modeled by other sections in NEFSC. If so, then some of these models will also need to be used when constructing operating models to support the implementation of the longer term EBFM strategy outlined in the NEFMC White Paper (although the Atlantis model developed for the NES LME can be used to evaluate these other aspects of EBFM). The difference in focus on trophic impacts between the NE US and SE Australia may in part reflect differences in the structure of those ecosystems and also perhaps the overall intensity of fishing in each region and the likelihood of trophic impacts arising. An alternative explanation is that the lower prominence given to the potential importance of trophic impacts in SE Australia simply reflects the lack of data (particularly diet data) to support understanding and modeling such effects in that region. The data and models examined in this review do generally support the likely importance of such effects in the NES LME (consistent with results from models and data for other well studied regions of the world) and therefore the need to consider them in developing ecosystem approaches to fisheries management in this region. But the point remains that more direct ecological impacts of fishing also need to be considered in formulating and implementing EBFM strategies.

As noted above, creating the ability to undertake MSE analyses and examine tradeoffs is an important part of the overall EM strategy. Several of the models that have been developed are suitable as operating models in various sorts of MSE, depending on the strategies being tested and the issues being investigated. For example if the focus is mainly on production potential and broad tradeoffs in exploitation levels across species and trophic levels, then several of the aggregate and multispecies production models constitute a suitable suite of operating models to explore the tradeoffs (and some have already been used in this way to explore this issue). To test the much broader-based strategies in the vision for regional EBFM and even more for multi-sector ocean use, spatially disaggregated full system models such as Atlantis are most suited to act as operating models. Other models could also serve in this capacity (see section 2E) but all require some level of further development. Overall, the full utilization of the capacity developed in the EM strategy to undertake MSE still lies mainly in the (near term) future.

As already noted, the future focus on developing and testing overall strategies for EBFM will be greatly influenced by whether and how key recommendations in the NEFMC White Paper are adopted and implemented. If this proceeds smoothly, then the EM capability in the EAP, coupled with expertise with more direct impacts of fishing elsewhere in NEFSC, should be well placed to support the process. If this process gets stalled or fails to eventuate, and there is still a desire and will to pursue the EBFM focus at NEFSC, then a complementary strategy to build support for the process might be considered. My own experience in Australia (admittedly in different institutional and other circumstances) might suggest a way forward. With encouragement (funding) from the relevant management authorities (both fisheries and ocean policy), we put together a coalition of managers, key industry leaders, NGOs and scientists to undertake a "whole of fishery" MSE for federally managed fisheries in southeastern Australia. While this was initially seen by many stakeholders as a (possibly interesting) academic exercise, we obtained surprisingly rapid buy-on and even enthusiasm once they understood the full potential and scope of investigating "what if" scenarios through an MSE process. Moreover the project (known as the AMS or Alternative Management Strategies project) proved to be a major catalyst leading to rapid and far-reaching changes in management of the suite of fisheries in the region. One of the early strategies identified, labeled in the initial MSE analysis as "blue skies" (i.e. radically different from then current management arrangements and unlikely to be a serious practical option), was largely implemented in the fishery in the space of about three years. A key aspect of the buy-in was very active stakeholder engagement in the MSE process itself, particularly in identifying objectives (including environmental, economic, social, and aspects of governance – particularly cost effective management) and in identifying management strategies (how would <u>you</u> manage this suite of fisheries) and then testing all options. I will not burden this review with further detail on the study and its approach and outcomes (see Smith et al. 2009 and Fulton et al. 2011b), but I am happy to provide more detail and copies of unpublished reports if there is interest.

A final point to note is that the analysis just described relied on considerable input from economists and had a strong “social science” focus as well. While the focus of the present review is on EM and therefore on the ecological and environmental aspects of EBFM, integrating economic and social dynamics into models is vital (e.g. see Fulton et al. 2011a) and should be part of any modeling strategy going forward, particularly in MSE analyses where economic and social objectives sit side by side with ecological and environmental objectives. This is equally important whether the focus is EBFM or EBM.

Recommendations

With regard to the overall strategy for ecosystem modeling at NEFSC in support of EBFM and Ocean Policy, the following recommendations should be considered:

1. Broaden the scope of the models, particularly those used as operating models to test EBFM strategies, to include direct impacts of fishing on species and habitats, to complement the focus on the trophic impacts of fishing.

2. Extend EM models with input from economic and social scientists to allow greater focus on behavioral aspects of human uses of the marine environment, and to facilitate the evaluation of the economic and social consequences of alternative management strategies (for both EBFM and EBM).

3. Depending on the outcome of the NEFMC White Paper process, consider an “AMS” style project to help build stakeholder understanding of and support for EBFM.

4. Continue to develop models and tools that incorporate multiple uses of the marine environment to support implementation of Ocean Policy. These models should have a strong spatial focus.

5. Consolidate the work to date on multi-model inference with a view to producing a major publication on this topic drawing on the experience in the NES LME.

C. ***Determine whether the science reviewed is considered to be the best scientific information available.***

The review of the science underpinning the overall modeling strategy is considered in more detail in section 2 of this report. Overall, the conclusion is that the science is of a very high standard and presents the best scientific information available to support EBFM for the region, though improvements in detail are possible and ongoing, as noted in section 2. This term of reference, focusing on the science itself, is not dealt with further in this section of the report, which focuses on the overall EM strategy.

D. ***Determine if the intended uses of overall community-ecosystem level modeling that have been identified as priorities for the NEUS LME are being executed in accordance with global best practices.***

Global best practice in ecosystem modeling and its application to EBFM and EBM is an evolving standard. Recent reviews and statements of this standard include Plaganyi (2007), FAO (2008) and Link et al. (2010a). Key aspects of the standard include:

1. Models should be fit for purpose
2. Models should be carefully documented
3. There should be explicit treatment of uncertainty
4. There should be a formal process to review models
5. The need to consider alternative formulations for species and group interactions
6. Approaches to model complexity and simplification (amalgamation of species and groups, spatial disaggregation)
7. Development and use of operating models for MSE

Several of these issues are addressed directly in Link et al. (2011) in the section of that report on “Best Practices for NEFSC Ecosystem Modeling” and the subsequent section on “Appropriateness of Review Venues for Various Model Classes”. The report documents how issues 2, 3, 5 and 7 have been addressed in the overall EM strategy at NEFSC. This review supports those statements. Model documentation is extensive and generally of a high standard. The multi-model inference approach addresses points 3, 5 and 6, with extensive sensitivity analyses within model types also a feature of many of the models reviewed. Several of the models also incorporate a formal statistical approach to model fitting, although this is by no means straightforward for many types of ecosystem model and impossible for some. Where formal approaches are not possible, there is extensive use of existing data to parameterize models and serious attempts are made to compare model predictions with data, including development of criteria for such comparisons in the PREBAL approach.

With regard to point 2 (model review), this review of course constitutes part of that process. As noted in section 2 of this report, the number and variety of models presented for review has not allowed the detailed scrutiny of each model that might be warranted. I agree with the statement made in Link et al. (2011) that review of ecosystem models needs to be undertaken by "a subtly but importantly different set of expertise" than is usual for review of stock assessment models. In particular, the standards by which the suitability of operating models for MSE should be judged to provide strategic advice are different than the standards by which assessment models should be judged to provide tactical advice.

This review deals fairly extensively with point 7 in the standards. While the amount of formal MSE undertaken to date is fairly limited, and much of it has focused on the issue of production potential and identification of ecosystem-level BRPs, the EM strategy has placed the NEFSC in a strong position to undertake further MSE work in support of EBFM and EBM, noting that further development of some of the models is still required. However the focus of the strategy on MSE is fully consistent with the best practice standard. The issue of models fit for purpose (point 1) is addressed in part 2 of this report.

The overall finding is that the EM strategy at NEFSC is consistent with global best practice approaches to ecosystem modelling, noting that standards in this area are still evolving. Indeed members of the EM team at NEFSC have made substantial and important contributions to the evolution of these standards, both nationally through the NEMoW process, and internationally through collaborative studies, contributions to debate on standards through ICES and FAO, and development of explicit criteria for judging model performance such as PREBAL.

E. Provide recommendations for further improvements.

The key recommendations on the overall EM strategy are listed above in section 1A and are not repeated here. The strategy to date has focused on building a suite of models and model types to underpin future implementation of EBFM in the region. This strategy has been successful in building a very strong capability base, but less successful so far in uptake, for some of the reasons already discussed and notwithstanding fairly extensive stakeholder engagement. The future EM strategy will depend on future demand from various sources, including both the fishery management process (particularly implementation of an overarching EBFM strategy through the regional fishery management council process) and implementation of Ocean Policy. Both these demands could increase quickly and substantially. If they do, then **the EM strategy should increase its current focus on developing and applying operating models that can support MSE analyses of broad strategies for EBFM and EBM** – a recommendation already implicit in the stated objective to "increase the focus on tradeoffs" in the EM strategy. There was strong support at the workshop for an MSE and multiple use focus from the MAFM Council member present. If resources are fixed, this would imply a decrease in focus in other areas. However **a serious increase in demand on either or both fronts (EBFM and Oceans Policy) will require a substantial increase in resources allocated to EM and associated tool development in the region**.

2. Evaluation of strengths and weaknesses, and recommendations for specific methodologies

The terms of reference for the review specified the following considerations for each model and method: Data requirements; adequacy of input data; strengths and weaknesses of analytical methodologies; Evaluate if model structure, parameterization, calibration/tuning, validation/verification, and intended uses are adequately documented; Evaluate strengths and weaknesses of assumptions, example estimations, and sources of uncertainties, especially with respect to known best practices in the field; Review types/levels of use for model outputs, especially with respect to adequacy of modeling relative to major topical issues; Recommendations.

A large number of background papers were made available to the review panel prior to the review workshop (Attachment 2), divided into different types of model according to the sections listed below (see also Figure 1 in Link et al. 2011). In addition, a presentation on each model type and on several additional cross-cutting topics was given during the workshop (Attachment 3). Given the very large number of models presented and the limited time available for the review, it was not possible to comprehensively review each model or to address all the terms of reference for each model type. Nevertheless the following sections present overall findings for each model type with associated specific recommendations focusing on key issues for each type of model. It should also be noted that one of the strengths of the approach taken to EM in the NEFSC is the diversity of approaches and model types used. Considering models and model types one by one does not fully recognize this strength, but the strengths and weaknesses of the overall approach are considered in more detail in part 1 of this report, as well as in the final section on Conclusions and Recommendations. Where possible I draw attention to the more specific role of each model or model type in the larger enterprise.

A. Energy Transfer Models (Fogarty) - Production Potential Models

This topic was covered in presentation 4 and in the background paper by Fogarty et al. (2008). These models are referred to in Link et al. (2011) as linear and stochastic production potential models (see Tables 1 and 2 therein). In the broader framework of Figure 1, they are a subset of full ecosystem models but of a particularly simple form representing energy transfer from primary production through a set of trophic levels. Their primary purpose is to assess the total fishery production potential of an ecosystem – in Fogarty et al. (2008) for the NE continental shelf of the US. This in turn could be used to set an upper constraint on total system removals (including, potentially, the consumption needs of threatened and endangered species and upper level predators that may be the subject of a recovery plan). Link et al. (2011) note that these models were previously reviewed as part of GARM III (NEFSC 2008).

Data requirements for these models are fairly modest and include net primary production, ecological transfer efficiencies by trophic level, consumption needs of top predators, and trophic level of the catch. The stochastic version allows input of distributions of these parameters, resulting in a posterior probability distribution of production potential. These models are not formally fitted to data (as in stock assessment models) but the various parameters can be estimated from existing data using more or less formal methods and uncertainties can be included as noted above.

Strengths of the method include its relative simplicity, its ease of communication, and its formal treatment of uncertainty. Weaknesses include its highly aggregated structure. Fogarty et al. (2008) compare the estimates produced for the NE shelf with similar estimates from other methods and previous studies (which range quite widely).

Findings: Production potential models are suitable for estimating potential caps on total system removals, particularly if multi-model comparisons are made with a range of other methods, including some of those reviewed in this report, to check for robustness of such estimates.

B. Energy Transfer Models (Link) - Network Models

This topic was covered in presentation 3 and in a series of background papers provided prior to the review including Link et al. (2006), Overholtz and Link (2009), Link (2010), Link et al. (2009), Link et al. (2008), Gaichas et al. (2009), Link et al. (2008), Link (2002), Pranovi and Link (2009), Link et al. (2008) and Fogarty et al. (2008). These models are referred to in Link et al. (2011) as network models (see Tables 1 and 2 therein) and include mass balance models such as Ecopath and Econetwrk, dynamic simulation models such as GOMAGG, and topological webs. In the broader framework of Figure 1, they are a subset of ecosystem models referred to as full network models or dynamic network models, and are also referred to as food web models. The focus of much of this work in the NEFSC has been in the EMAX project (Energy Modeling and Analysis eXercise). The models have been developed and used for a range of scientific purposes, including data synthesis, fundamental studies of energy flow and comparative studies across ecosystems, as well as for more applied purposes such as development of ecosystem indicators and exploration of scenarios of system change including climate change (Link et al. 2011). Other uses have included estimating production potential caps, examining the “ecological footprint” of fish predators, and examining the role of marine mammals and seabirds in the ecosystem. Given the extent and diversity of this program of work, it is not possible to address all the terms of reference for this suite of models. Instead I focus on selected issues, outlined below.

Ecopath is the most widely used ecosystem-level model currently in use, and much of the NEFSC food web modeling has used Ecopath. However it is notable and commendable that a range of similar models and methods has also been used to check for robustness of results and sensitivity to model assumptions. At least four Ecopath models have been developed for various parts of the NE US, drawing on and making good use of the extensive data sets (including surveys and diet information) available for the region. Notwithstanding the excellent data available (in comparison to most other regions of the world), the analyses have revealed some important gaps in data, particularly with regard to non-commercial species and groups. Some evidence was presented that gaps identified through the EM process have helped inform data collection strategies for the region, though implementation is subject to a range of priorities and some gaps still remain. An important innovation in the body of work, and one that deserves wider notice, is the development of the PREBAL approach (Link 2010) that provides diagnostics for network models that can be used in model development and review. Another positive feature of the use of mass balance models such as Ecopath in the NEFSC is the extensive use of sensitivity analysis to data and parameter uncertainty. In summary, the extensive development and use of mass balance network models in the region provides a very firm foundation for further development of dynamic ecosystem models that can be used to address a range of strategic management questions and issues. The comparative studies with other regional ecosystems also provide an important contribution to the understanding of the trophic dynamics of fished ecosystems more generally.

While presentation 3 provided some early results from the extension of the static Ecopath to the dynamic Ecosim models, this work is still clearly at an early stage of development (but should be continued). However a dynamic network simulation model for the Gulf of Maine – GOMAGG – has been developed at NEFSC and a background paper was provided for the review (Overholtz and Link 2009). As the publication states, this model was developed “to address the gap between Ecosim and some of the more detailed ecosystem models such as Atlantis”. Like Ecosim, it builds on the mass balance framework provided by Ecopath, and uses the same biomass update equation as is used in Ecosim. It differs from Ecosim in the equation used to represent predation, and as the paper notes, the equation used generally results in a Holling type II functional response. The published paper uses the model to explore a range of future scenarios including changes in primary productivity, the abundance of small pelagic fish, the abundance of top predators, fishing mortality rates on various groups, and various combinations of these scenarios. The main finding is that the Gulf of Maine ecosystem tends to be driven from the bottom up (consistent with other studies) and is generally robust to structural changes in abundance of top order predators. While the model is based on a lot of data and structural knowledge summarized in the extensive Ecopath work referred to previously, no attempt has been made to compare the dynamic simulations to time series of historical data (i.e. the model has not been tuned to historical data). This seems like an obvious next step. It is also widely recognized that ecological models can be sensitive to the way in which predation is portrayed (e.g. Fulton et al. 2003). Sensitivity to this source of uncertainty could be explored either by varying the formulation for predation within the model or by comparing the model dynamics and predictions with an Ecosim model for the same system (which uses the foraging arena formulation for predation).

As outlined in the background section of this report, one of the main purposes of the review is to “evaluate the appropriateness and performance characteristics of community-level and ecosystem models employed at NEFSC as operating models in support of the development of Ecosystem-Based Fishery Management (EBFM) strategies for the Northeast U.S. Continental Shelf”. Both the GOMAGG model and the (still under development) Ecosim models are clearly suitable for use as operating models in testing various aspects of strategies for EBFM, though both model types would benefit from further verification (comparison with historical time series data). As operating models, they could be used to explore issues such as system level caps on production and the use of “two tier” harvest strategies, as well as the implications of managing some parts of the ecosystem (e.g. groundfish, small pelagics, benthic invertebrates) for other parts (including protected or recovering species) and the tradeoffs involved.

C. Aggregate Production Models (Link/Fogarty)

This topic was covered in presentation 7 and in the background papers by Link et al. (2010), Overholtz et al. (2007), Overholtz et al. (2008) and Link et al. (2008). These models are referred to in Link et al. (2011) as aggregate production models (see Tables 1 and 2 therein). In the broader framework of Figure 1, they are a subset of multispecies models that include (some) biological interactions among groups but do not represent age or size structure. Their primary purpose so far is to explore broad tradeoffs in exploiting different components of the ecosystem in simple MSE analyses.

This suite of models represents variations of a multispecies logistic or Schaefer model with species grouped into various guilds (e.g. flatfish, groundfish, forage fish and elasmobranchs) rather than represented individually. The range of models in this category is listed in Table 2 of Link et al. (2011) and is quite extensive. The relative simplicity of the models allows some aspects of formal fitting to data, though where biological interactions are included these parameters are generally drawn from other studies. An interesting feature of the analyses presented examined depletion levels across species within guilds to determine tradeoffs between overall guild exploitation rates and catch levels against depletion levels of individual species. This starts to identify BRPs associated with caps (total system productivity) and floors (no species collapsed) that meets one of the overall objectives of the EM strategy (to identify system level reference points) and is a valuable outcome of this modeling approach. The approach will also be useful in evaluating broad strategies for the longer term implementation of EBFM into regional plans, where tradeoffs across fisheries will have to be addressed. This provides a nice complement to the more detailed system level models that will also be used to evaluate such strategies.

D. Multispecies Production Models (Gamble/Fogarty)

This topic was covered in presentation 5 and in the background papers by Gamble and Link (2009) and Link (2003). These models are referred to in Link et al. (2011) as multispecies production models (see Tables 1 and 2 therein) and include MS-PROD. In the broader framework of Figure 1, they are a subset of multispecies models referred to as community level models. Their primary purpose is very similar to the aggregate production models discussed in the previous section.

The main model presented was MS-PROD (Gamble and Link 2009) which is based around the Schaefer production model applied at various levels of aggregation from individual species up to guilds (at which point it is similar to the models reviewed in section 2C). It has been used to look at the relative importance of predation, competition (within and between guilds) and fishing mortality. As currently implemented, MS-PROD is a simulation tool and is not fitted to data. More work is needed to establish the credibility of the parameters selected, by comparing model output to historical time series data for major groups represented in the model. The model is simple enough to allow formal fitting though probably not with all biological interaction terms switched on. The data needs are fairly modest. While sensitivity analyses are possible and have been explored, further work is required to determine how to represent uncertainties in predictions. With some further work, the model looks to be useful as an operating model to explore tradeoffs among fisheries given a two-tiered harvest strategy embracing overall caps and individual species limits on catch. One of its main virtues in an MSE context is that it is very fast to run so that extensive robustness testing should be possible.

E. Full System Models (Link/Gamble) - ATLANTIS

This topic was covered in presentation 8. These models are referred to in Link et al. (2011) as full system models (see Tables 1 and 2 therein) with the single regional example being the NE US version of Atlantis (Link et al. 2010 with a supporting technical document on model calibration). In the broader framework of Figure 1, Atlantis is an example of a full ecosystem model categorized as age/size/space structured models. Atlantis is intended as an operating model for strategic evaluation of whole of system management strategies and is not intended to provide tactical advice.

Atlantis is by far the largest and most complex ecosystem model developed in the region and in its current form represents the product of 2 to 3 years research time and effort. It includes a lot of spatial structure, a full ecosystem model (including 45 biological groups), representation of all the main fleets and fisheries in the region, and has the ability to explore a very diverse set of management options that can be bundled in various ways into regional management strategies. In principle it can also be used to represent diverse uses of the marine environment other than fishing. It is not user friendly, is very slow to run, and is extremely challenging to parameterize. Formal fitting to data is impossible with such a large model, but a four stage calibration process has been applied to match as nearly as possible model predictions with historical data. Further calibration effort is required (e.g. comparing predictions post 2004 with observed trends in key groups) and no doubt further will be required when additional forward predictions are examined. In general, the model now fits broad trends in historical time series. There was some debate about the “tolerance” to be applied in such fitting, and about why the model might not fit some of the variation around these trends, but it is unlikely to ever fit all such higher frequency variation across so many groups. The model was seen to do a reasonably good job of fitting key ecological groups and those with better data. An example of the use of the model was presented, to examine the relative effects of climate, fishing and predation.

While the model has not been used so far to provide even strategic advice, there was general acceptance that it could be used as a simulation tool to examine a range of broader issues discussed during the workshop, including the robustness of some of the simpler models (making use of its data generating facility). In principle, it can be used to examine aspects of all of the issues that the overall EM strategy is designed to address (see section 1A). In particular, its ability to explore the consequences of spatial management in many forms lends itself to application in an MSE sense for designing and testing both EBFM and Ocean Policy strategies.

As noted in the presentation and in Link et al. (2011), the strengths of Atlantis include its modular structure and flexibility in process representation, its explicit incorporation of physics, ecology, economics and human use and behavior, its spatial structure, and its explicit design to facilitate use in an MSE context. Its chief drawbacks are its ease of use, its long run and calibration times, and the difficulty of fully embracing the wide range of uncertainties inherent in such a complex model. With regard to the drawbacks, this suggests that additional effort should continue to be invested in simpler alternatives that combine some of its key features. These might include extending the current Ecopath models to Ecosim and Ecospace, and perhaps ongoing development of models such as GOMAGG. This would continue the EM strategy of using comparisons across multiple models at different levels of complexity to check for robustness of results to model uncertainty.

F. Other models (Fogarty/Link)

F1. Empirical multivariate time series

This topic was covered in presentation 2 with no background papers provided prior to the review. These models are referred to in Link et al. (2011) as multi-variate time series models. In the broader framework of Figure 1, they are non-mechanistic models referred to as empirical multi-variate models, including both linear and non-linear state space models.

These are the simplest models of all the classes presented in the review. The simplicity is a virtue in two respects. They can be fitted directly to time series data (where they show good forecast skill) and their stability properties can be analysed, potentially leading to inference about global stability properties (including threshold effects) of the systems they represent. They are unlikely to be used to provide either tactical or strategic advice to management, but they may play a useful role in informing the development and use of more complex models. For example they have been used to infer where non-linear processes may be driving key system variables.

F2. Extended Stock Assessment Models (ESAMs)

This topic was covered in presentation 6 and in the background papers by Hare et al. (2010) and NEFSC (2011). These models are referred to in Link et al. (2011) in the section on minimum realistic models and include models that extend single species assessments to include, in particular, predation mortality (see pp 16-23). In the broader framework of Figure 1, they are a subset of multispecies models and include models that use age structure and others that do not.

This is a diverse class of models with many examples developed for the NES LME. They serve the primary (potential) purpose of underpinning the transition strategy to EBFM outlined in the NEFMC White Paper – dealing with species interactions in the context of existing management structures. This set of models addresses the impact of consumptive removals on single species models, in particular leading to time varying estimates for natural mortality due to predation. A second class also deals with environmental drivers leading to time varying parameters in single species stock assessment models (including r and K or their equivalents). The presentation showed a range of analyses of ecological footprint, ecological interactions, and environmental interactions, applied to a wide range of species. Overall (and without detailed critical review), the methods and the data underpinning them appear to be robust. Many of the models are fit directly to data and the fitting methods appear to be as robust as those used in typical single species assessments. Some of the assumptions were queried but the overall picture is of effects of predation on M that are both substantial and time varying, across a range of assumptions and model formulations. While several of these analyses have been used to provide "context" for single species assessments, only one of the analyses appears to have been used directly in a stock assessment model to provide tactical advice. While some of the reasons for this were discussed at the workshop and are mentioned in section 1A of this report, this represents a very poor return on considerable investment. The EAP should consider their investment in this type of model pending clarification of proper mechanisms for uptake, such as acceptance of the broad strategy for implementation of EBFM outlined in the NEFMC White Paper.

Conclusions and Recommendations

The terms of reference for this review address two different aspects of the development and use of ecosystem modeling in the NEFSC. The first concerns the overall strategy for ecosystem modeling in the NEFSC. The second concerns the robustness of particular models and model types used in the overall strategy. While both terms of reference were addressed to some extent in this review, by far the greater focus has been on the overall strategy, and the recommendations arising in the review pertain to this aspect of the work, as outlined below.

With regard to the overall strategy for ecosystem modeling at NEFSC in support of EBFM and Ocean Policy, the following recommendations should be considered (for context see section 1A of this report):

1. Broaden the scope of the models, particularly those used as operating models to test EBFM strategies, to include direct impacts of fishing on species and habitats, to complement the focus on the trophic impacts of fishing.

2. Extend EM models with input from economic and social scientists to allow greater focus on behavioral aspects of human uses of the marine environment, and to facilitate the evaluation of the economic and social consequences of alternative management strategies (for both EBFM and EBM).

3. Depending on the outcome of the NEFMC White Paper process, consider an "AMS" style project to help build stakeholder understanding of and support for EBFM.

4. Continue to develop models and tools that incorporate multiple uses of the marine environment to support implementation of Ocean Policy. These models should have a strong spatial focus.

5. Consolidate the work to date on multi-model inference with a view to producing a major publication on this topic drawing on the experience in the NES LME.

In addition to these specific recommendations, section 1D of this report also provided the following advice:

> The future EM strategy will depend on future demand from various sources, including both the fishery management process (particularly implementation of an overarching EBFM strategy through the regional fishery management council process) and implementation of Ocean Policy. Both these demands could increase quickly and substantially. If they do, then **the EM strategy should increase its current focus on developing and applying operating models that can support MSE analyses of broad strategies for EBFM and EBM** – a recommendation already implicit in the stated objective to "increase the focus on tradeoffs" in the EM strategy. There was strong support at the workshop for an MSE and multiple use focus from the MAFMC council member present. If resources are fixed, this would imply a decrease in focus in other areas. However **a serious increase in demand on either or both fronts (EBFM and Oceans Policy) will require a substantial increase in resources allocated to EM and associated tool development in the region**.

In addition to specific recommendations, reviewers were asked to provide a critique of the NMFS review process, including suggestions for improvements of both process and products. My comments in this regard are as follows:

> The logistic arrangements for the review were highly efficient and professional. The background material was provided on time and the key summary document for the review (Link et al. 2011) provided an excellent and very well structured overview of the EM strategy and content, addressing all the significant aspects of the terms of reference. The organization for the workshop was excellent and the presentations highly professional. There was good attendance at the workshop (see Attachment 5) and good engagement from several of those attending. In particular it was very helpful to have a member of one of the regional fishery management councils present throughout the workshop. I would like to thank the members of the Ecosystem Assessment Program, and in particular Mike Fogarty and Jason Link, for the huge effort put into providing and presenting material to facilitate the work of the reviewers, and for the professional quality of that material.
>
> The only criticism I have of the process (but it is a significant one) is that it proved impossible to meet fully all the terms of reference of the review because of the

enormous amount of material that was put forward for review. Given the time constraints it proved impossible to do justice to all this material, and my review has focused largely on the first aspect of the terms of reference (assessing the overall EM strategy) and has not provided the detailed critical review of each of the models and methods that seemed to be expected. While I have made comments on each of the model types listed in the terms of reference, this falls way short of fully meeting the terms of reference associated with review of each model type. The advice therefore is to more fully consider the scope of the terms of reference and the number of models to be considered in future reviews of this nature.

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Attachment 1: Bibliography of materials provided for review

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Attachment 2: Statement of Work

External Independent Peer Review by the Center for Independent Experts

Review of Modeling Approaches in Support of Ecosystem-Based Fishery Management

Scope of Work and CIE Process: The National Marine Fisheries Service's (NMFS) Office of Science and Technology coordinates and manages a contract providing external expertise through the Center for Independent Experts (CIE) to conduct independent peer reviews of NMFS scientific projects. The Statement of Work (SoW) described herein was established by the NMFS Project Contact and Contracting Officer's Technical Representative (COTR), and reviewed by CIE for compliance with their policy for providing independent expertise that can provide impartial and independent peer review without conflicts of interest. CIE reviewers are selected by the CIE Steering Committee and CIE Coordination Team to conduct the independent peer review of NMFS science in compliance the predetermined Terms of Reference (ToRs) of the peer review. Each CIE reviewer is contracted to deliver an independent peer review report to be approved by the CIE Steering Committee and the report is to be formatted with content requirements as specified in **Annex 1**. This SoW describes the work tasks and deliverables of the CIE reviewer for conducting an independent peer review of the following NMFS project. Further information on the CIE process can be obtained from www.ciereviews.org.

Project Description: The purpose of this review is to evaluate the appropriateness and performance characteristics of community-level and ecosystem models employed at NEFSC as operating models in support of the development of Ecosystem-Based Fishery Management (EBFM) strategies for the Northeast U.S. Continental Shelf. NMFS strongly endorsed the concept of Ecosystem-Based Management and the related need for the development of Integrated Ecosystem Assessment in support of EBFM. Although this review is directed at efforts in the NEFSC, the findings will be more broadly applicable throughout the agency. The Terms of Reference (ToRs) of the peer review are attached in **Annex 2**. The tentative agenda of the panel review meeting is attached in **Annex 3**.

Requirements for CIE Reviewers: Three CIE reviewers shall conduct an impartial and independent peer review in accordance with the SoW and ToRs herein.

CIE reviewers shall have working knowledge and recent experience in the application of community-level and ecosystem models for EBFM. The CIE reviewers shall have expertise with a broad spectrum of complexity and mechanistic detail from static energy flow models to detailed simulation models, and familiarity with the ATLANTIS model is desirable. Our objective is to employ multi-model inference to assess options for EBFM. We are particularly interested in the question of tradeoffs between model complexity and predictive skill in meeting the needs for scientific advice in support of EBFM. Operating models lie at the heart of the development of Integrated Ecosystem Assessments (IEAs). IEAs have been strongly advocated at the agency level as the principle vehicle for developing and evaluating scientific advice in support of EBFM. It is essential that a rigorous review of modeling activities be undertaken to meet this need.

CIE reviewers shall have experience in different approaches to modeling exploited marine ecosystems. The approaches currently employed in this region include mass balance energy flow models, aggregate-species production models with implicit consideration of species interactions, multispecies production models with explicit consideration of interspecific interactions, state-space multispecies models, multispecies delay-difference models, and the ATLANTIS modeling framework. Reviewers shall have direct experience in model development with EBFM application.

Each CIE reviewer's duties shall not exceed a maximum of 14 days to complete all work tasks of the peer review described herein.

Location of Peer Review: Each CIE reviewer shall conduct an independent peer review during the panel review meeting scheduled in Woods Hole, Massachusetts during 29-31 March 2011.

Statement of Tasks: Each CIE reviewers shall complete the following tasks in accordance with the SoW and Schedule of Milestones and Deliverables herein.

Prior to the Peer Review: Upon completion of the CIE reviewer selection by the CIE Steering Committee, the CIE shall provide the CIE reviewer information (full name, title, affiliation, country, address, email) to the COTR, who forwards this information to the NMFS Project Contact no later the date specified in the Schedule of Milestones and Deliverables. The CIE is responsible for providing the SoW and ToRs to the CIE reviewers. The NMFS Project Contact is responsible for providing the CIE reviewers with the background documents, reports, foreign national security clearance, and other information concerning pertinent meeting arrangements. The NMFS Project Contact is also responsible for providing the Chair a copy of the SoW in advance of the panel review meeting. Any changes to the SoW or ToRs must be made through the COTR prior to the commencement of the peer review.

Foreign National Security Clearance: When CIE reviewers participate during a panel review meeting at a government facility, the NMFS Project Contact is responsible for obtaining the Foreign National Security Clearance approval for CIE reviewers who are non-US citizens. For this reason, the CIE reviewers shall provide requested information (e.g., first and last name, contact information, gender, birth date, passport number, country of passport, travel dates, country of citizenship, country of current residence, and home country) to the NMFS Project Contact for the purpose of their security clearance, and this information shall be submitted at least 30 days before the peer review in accordance with the NOAA Deemed Export Technology Control Program NAO 207-12 regulations available at the Deemed Exports NAO website: http://deemedexports.noaa.gov/sponsor.html).

Pre-review Background Documents: Two weeks before the peer review, the NMFS Project Contact will send (by electronic mail or make available at an FTP site) to the CIE reviewers the necessary background information and reports for the peer review. In the case where the documents need to be mailed, the NMFS Project Contact will consult with the CIE Lead Coordinator on where to send documents. CIE reviewers are responsible only for the pre-review documents that are delivered to the reviewer in accordance to the SoW scheduled deadlines specified herein. The CIE reviewers shall read all documents in preparation for the peer review.

The reviewers will be supplied with a review document describing ongoing modeling efforts at NEFSC in support of ecosystem-based fishery management:

Community and Ecosystem Models in Support of Ecosystem-Based Fishery Management for the Northeast U.S. Continental Shelf. Projected length 125-150 pp maximum

Panel Review Meeting: Each CIE reviewer shall conduct the independent peer review in accordance with the SoW and ToRs, and shall not serve in any other role unless specified herein. **Modifications to the SoW and ToRs can not be made during the peer review, and any SoW or ToRs modifications prior to the peer review shall be approved by the COTR and CIE Lead Coordinator.** Each CIE reviewer shall actively participate in a professional and respectful manner as a member of the meeting review panel, and their peer review tasks shall be focused on the ToRs as specified herein. The NMFS Project Contact is responsible for any facility arrangements (e.g., conference room for panel review meetings or teleconference arrangements). The NMFS Project Contact is responsible for ensuring that the Chair understands the contractual role of the CIE reviewers as specified herein. The CIE Lead Coordinator can contact the Project Contact to confirm any peer review arrangements, including the meeting facility arrangements.

The CIE peer reviewers will provide a critical evaluation of the community-level and ecosystem modeling conducted at NEFSC in support of EBFM. The adequacy of the overall modeling framework to meet the needs of EBFM in this region will be assessed and recommended changes to modeling strategies will be provided. The reviewers will contribute individual perspectives on the findings and recommendations for each ToRs. The panel Chair will be responsible for overall compilation of the report of the peer review and in the development of a summary statement of the adequacy of the modeling effort in relationship to the requirements for EBFM in this region.

Contract Deliverables - Independent CIE Peer Review Reports: Each CIE reviewer shall complete an independent peer review report in accordance with the SoW. Each CIE reviewer shall complete the independent peer review according to required format and content as described in Annex 1. Each CIE reviewer shall complete the independent peer review addressing each ToR as described in Annex 2.

Other Tasks – Contribution to Summary Report: Each CIE reviewer may assist the Chair of the panel review meeting with contributions to the Summary Report, based on the terms of reference of the review. Each CIE reviewer is not required to reach a consensus, and should provide a brief summary of the reviewer's views on the summary of findings and conclusions reached by the review panel in accordance with the ToRs.

Specific Tasks for CIE Reviewers: The following chronological list of tasks shall be completed by each CIE reviewer in a timely manner as specified in the **Schedule of Milestones and Deliverables**.

1) Conduct necessary pre-review preparations, including the review of background material and reports provided by the NMFS Project Contact in advance of the peer review.
2) Participate during the panel review meeting at the Northeast Fisheries Science Center in Woods Hole, Massachusetts during 29-31 March 2011.
3) At the Northeast Fisheries Science Center in Woods Hole, Massachusetts during 29-31 March 2011 as specified herein, conduct an independent peer review in accordance with the ToRs (**Annex 2**).
4) No later than 14 April 2011, each CIE reviewer shall submit an independent peer review report addressed to the "Center for Independent Experts," and sent to Mr. Manoj Shivlani, CIE Lead Coordinator, via email to shivlanim@bellsouth.net, and to Dr. David Sampson, CIE Regional Coordinator, via email to david.sampson@oregonstate.edu. Each CIE report shall be written using the format and content requirements specified in Annex 1, and address each ToR in **Annex 2**.

Schedule of Milestones and Deliverables: CIE shall complete the tasks and deliverables described in this SoW in accordance with the following schedule.

22 February 2011	CIE sends reviewer contact information to the COTR, who then sends this to the NMFS Project Contact
15 March 2011	NMFS Project Contact sends the CIE Reviewers the pre-review documents
March 29-31 2011	Each reviewer participates and conducts an independent peer review during the panel review meeting
14 April 2011	CIE reviewers submit draft CIE independent peer review reports to the CIE Lead Coordinator and CIE Regional Coordinator
28 April 2011	CIE submits CIE independent peer review reports to the COTR
5 May 2011	The COTR distributes the final CIE reports to the NMFS Project Contact and regional Center Director

Modifications to the Statement of Work: Requests to modify this SoW must be approved by the Contracting Officer at least 15 working days prior to making any permanent substitutions. The Contracting Officer will notify the COTR within 10 working days after receipt of all required information of the decision on substitutions. The COTR can approve changes to the milestone dates, list of pre-review documents, and ToRs within the SoW as long as the role and ability of the CIE reviewers to complete the deliverable in accordance with the SoW is not adversely impacted. The SoW and ToRs shall not be changed once the peer review has begun.

Acceptance of Deliverables: Upon review and acceptance of the CIE independent peer review reports by the CIE Lead Coordinator, Regional Coordinator, and Steering Committee, these reports shall be sent to the COTR for final approval as contract deliverables based on compliance with the SoW and ToRs. As specified in the Schedule of Milestones and Deliverables, the CIE shall send via e-mail the contract deliverables (CIE independent peer review reports) to the COTR (William Michaels, via William.Michaels@noaa.gov).

Applicable Performance Standards: The contract is successfully completed when the COTR provides final approval of the contract deliverables. The acceptance of the contract deliverables shall be based on three performance standards:
(1) each CIE report shall completed with the format and content in accordance with **Annex 1**,
(2) each CIE report shall address each ToR as specified in **Annex 2**,
(3) the CIE reports shall be delivered in a timely manner as specified in the schedule of milestones and deliverables.

Distribution of Approved Deliverables: Upon acceptance by the COTR, the CIE Lead Coordinator shall send via e-mail the final CIE reports in *.PDF format to the COTR. The COTR will distribute the CIE reports to the NMFS Project Contact and Center Director.

Support Personnel:

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Key Personnel:

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Annex 1: Format and Contents of CIE Independent Peer Review Report

1. The CIE independent report shall be prefaced with an Executive Summary providing a concise summary of the findings and recommendations, and specify whether the science reviewed is the best scientific information available.

2. The main body of the reviewer report shall consist of a Background, Description of the Individual Reviewer's Role in the Review Activities, Summary of Findings for each ToR in which the weaknesses and strengths are described, and Conclusions and Recommendations in accordance with the ToRs.

   a. Reviewers should describe in their own words the review activities completed during the panel review meeting, including providing a brief summary of findings, of the science, conclusions, and recommendations.

   b. Reviewers should discuss their independent views on each ToR even if these were consistent with those of other panelists, and especially where there were divergent views.

   c. Reviewers should elaborate on any points raised in the Summary Report that they feel might require further clarification.

   d. Reviewers shall provide a critique of the NMFS review process, including suggestions for improvements of both process and products.

   e. The CIE independent report shall be a stand-alone document for others to understand the weaknesses and strengths of the science reviewed, regardless of whether or not they read the summary report. The CIE independent report shall be an independent peer review of each ToRs, and shall not simply repeat the contents of the summary report.

3. The reviewer report shall include the following appendices:

   Appendix 1: Bibliography of materials provided for review
   Appendix 2: A copy of the CIE Statement of Work
   Appendix 3: Panel Membership or other pertinent information from the panel review meeting.

Annex 2.1: Terms of Reference for the Peer Review

Review of Modeling Approaches in Support of Ecosystem-Based Fishery Management

1. Evaluation, findings and recommendations of overall community-ecosystem level modeling strategy
2. Evaluation of strengths and weaknesses, and recommendations of analytic methodologies
3. Evaluation and recommendations of model assumptions, estimates, and uncertainty
4. Evaluation, findings, and recommendations of result interpretation and conclusions
5. Determine whether the science reviewed is considered to be the best scientific information available.
6. Recommendations for further improvements
7. Brief description on panel review proceedings highlighting pertinent discussions, issues, effectiveness, and recommendations

Annex 2.2: Terms of Reference for the Peer Review provided at Review Panel Meeting

Review of Modeling Approaches in Support of Ecosystem-Based Fishery Management

A. Overall Review- Synthesis & Summary
   a. Summarize evaluations, findings and recommendations of overall community-ecosystem level modeling strategy in practice for the NEUS LMR system
   b. Determine whether the science reviewed is considered to be the best scientific information available.
   c. Determine if the intended uses of overall community-ecosystem level modeling that have been identified as priorities for the NEUS LME are being executed in accordance with global best practices.
   d. Provide recommendations for further improvements.
   e. Provide brief description on panel review proceedings highlighting pertinent discussions, issues, effectiveness, and recommendations

B. Energy Transfer Models *(Fogarty)- Production Potential Models*
   i. Review and agree upon data requirements requisite for the model
   ii. Evaluate adequacy of input data as applied for the NEUS application of this model
   iii. Evaluate strengths and weaknesses of analytical methodologies
   iv. Evaluate if model structure, parameterization, calibration/tuning, validation/verification, and intended uses are adequately documented
   v. Evaluate strengths and weaknesses of assumptions, example estimations, and sources of uncertainties, especially with respect to known best practices in the field
   vi. Review types/levels of use for model outputs, especially with respect to adequacy of modeling relative to major topical issues
   vii. Recommendations

C. Energy Transfer Models *(Link)- Network Models*
   i. Review and agree upon data requirements requisite for the model
   ii. Evaluate adequacy of input data as applied for the NEUS application of this model
   iii. Evaluate strengths and weaknesses of analytical methodologies
   iv. Evaluate if model structure, parameterization, calibration/tuning, validation/verification, and intended uses are adequately documented
   v. Evaluate strengths and weaknesses of assumptions, example estimations, and sources of uncertainties, especially with respect to known best practices in the field

vi. Review types/levels of use for model outputs, especially with respect to adequacy of modeling relative to major topical issues
vii. Recommendations

D. Aggregate Production Models *(Link/Fogarty)*
   i. Review and agree upon data requirements requisite for the model
   ii. Evaluate adequacy of input data as applied for the NEUS application of this model
   iii. Evaluate strengths and weaknesses of analytical methodologies
   iv. Evaluate if model structure, parameterization, calibration/tuning, validation/verification, and intended uses are adequately documented
   v. Evaluate strengths and weaknesses of assumptions, example estimations, and sources of uncertainties, especially with respect to known best practices in the field
   vi. Evaluate levels, methods and ramifications for aggregation and compare to single species summaries
   vii. Review types/levels of use for model outputs, especially with respect to adequacy of modeling relative to major topical issues
   viii. Recommendations

E. Multispecies Production Models *(Gamble/Fogarty)*
   i. Review and agree upon data requirements requisite for the model
   ii. Evaluate adequacy of input data as applied for the NEUS application of this model
   iii. Evaluate strengths and weaknesses of analytical methodologies
   iv. Evaluate if model structure, parameterization, calibration/tuning, validation/verification, and intended uses are adequately documented
   v. Evaluate strengths and weaknesses of assumptions, example estimations, and sources of uncertainties, especially with respect to known best practices in the field
   vi. Review types/levels of use for model outputs, especially with respect to adequacy of modeling relative to major topical issues
   vii. Recommendations

F. Full System Models *(Link/Gamble)- ATLANTIS*
   i. Review and agree upon data requirements requisite for the model
   ii. Evaluate adequacy of input data as applied for the NEUS application of this model
   iii. Evaluate strengths and weaknesses of analytical methodologies
   iv. Evaluate if model structure, parameterization, calibration/tuning, validation/verification, and intended uses are adequately documented

v. Evaluate strengths and weaknesses of assumptions, example estimations, and sources of uncertainties, especially with respect to known best practices in the field
vi. Evaluate levels, methods and ramifications for aggregation
vii. Review types/levels of use for model outputs, especially with respect to adequacy of modeling relative to major topical issues
viii. Recommendations

G. Other models *(Fogarty/Link)*

i. Briefly review and comment upon other community and ecosystem models for the NEUS ecosystem. For each:
   1. Review simple summaries
   2. Evaluate examples of intended/extant uses
   3. Identify any gaps in model uses
ii. Empirical multivariate time series
iii. MRMs
   1. ESAMs
   2. Other MS models
iv. Others
v. Recommendations

Attachment 3: Presentations at the workshop

Review of Modeling Approaches in Support of Ecosystem-Based Fishery Management

1. Toward Ecosystem-based Fishery Management on the Northeast U.S. Continental Shelf (Fogarty) [TOR 1]
2. A Review of Empirical Time Series Models (Fogarty) [TOR 2F1]
3. A Review of Energy Transfer (Network) Models (Link) [TOR 2B]
4. A Review of Fishery Production Potential Models (Fogarty) [TOR 2A]
5. A Review of Multispecies Production Models (Gamble) [TOR 2D]
6. A Review of Extended Stock Assessment Models (Link) [TOR 2F2]
7. A Review of Aggregate Production Models (Fogarty) [TOR 2C]
8. A Review of Full System Models (Link) [TOR 2E]
9. Discussion of Multi-Model Inference (Link)
10. Discussion on Model Uses for MSE (Link)

Attachment 4: Workshop attendance

Participants in the workshop on Review of Modeling Approaches in Support of EBFM Meeting 29/3/2011 - 31/3/2011

1. Ingrid Biedson – Cornell
2. Tom Hoff – MAFMC
3. Wendy Gabriel – NEFSC
4. Kiersten Curti – NEFSC
5. Rich Bell – URI/NMFS
6. Anne Richards – NEFSC
7. Sean Lucey – NEFSC
8. Steve Sutton – NEFSC
9. Ron Schlitz – NEFSC
10. Burton Shank – NEFSC
11. Linda Deegan – MBL
12. Hui Liu – NEFSC
13. Rob Gamble – NEFSC
14. Tony Smith – CSIRO Australia
15. Villy Christensen - UBC
16. Gunnar Stefausson – University of Iceland
17. Frank Almeida – NEFSC
18. Jon Hare – NEFSC – Narragansett
19. Michael Jones – NEFSC
20. Kimberly Murray – NEFSC
21. David McElroy
22. Laurel Col – NEFSC
23. Deborah Hart – NEFSC
24. Mike Fogarty – NEFSC
25. Jason Link – NEFSC

Attachment 5: Workshop program

Review of Modeling Approaches in Support of Ecosystem-Based Fishery Management

Northeast Fisheries Science Center, Woods Hole MA 02543

March 29-31 2011

March 29 2011

900 Welcome to Workshop and Overview of Objectives for the Review
930 Review of Overview Modeling Strategy and Philosophy for Multi-Model Inference (TOR A)
1030 Break
1100 Empirical Multivariate Models (TOR G)
1145 Review of Energy Transfer Models (TOR B)

1230 Lunch
1330 Review of Energy Transfer Models (TOR C)

1530 Break
1600 Discussion
1730 Adjourn main meeting
1730-1800 Panel Deliberations, as needed (TOR A)

March 30 2011

0900 Transition Approaches to Enhance Single Species Advice

1030 Break

1100 Review of Aggregate Production Models (TOR D)

1230 Lunch

1400 Review of Multispecies Production Models (TOR E)

1530 Break

1600 Discussion

1730 Adjourn main meeting

1730-1800 Panel Deliberations, as needed (TOR A)

March 31 2011

0900 Review of Full System Models (TOR F)

1030 Break

1100 Discussion of Model Uses for Production Potential, Ecosystem Overfishing & Related BRPs

1230 Lunch

1400 Discussion on Model Uses for MSE, Tradeoffs & Multisector Uses

1500 Panel Deliberations (TOR A)

1730 Adjourn